Radar Remote Sensing of Ice and Sea State and Air-Sea Interaction in the Marginal Ice Zone

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LONG-TERM GOALS

The goals of this project are to utilize shipborne remote sensing to understand the scattering and attenuation process of ocean waves interacting with ice. A dedicated nautical X-band radar on a vessel would be used to follow the propagation of waves into the marginal ice zone (MIZ) and observe the attenuation and scattering of wave modes from the floating ice as well as estimate surface wind and surface current speeds and directions. This measuring approach will provide a comprehensive local picture of wave scattering and boundary layer flows over floating ice in the MIZ.

OBJECTIVES

To determine the penetration distance of waves in the MIZ and correlate the MIZ width to the surface wave climatology that generated it.

1. To determine the density of ice floes in the MIZ similar to "void fraction" and correlate this parameter to the surface wave climatology.
2. To describe the local momentum transfer during freezing and melting cycles and the transport patterns affected by wind and currents.
3. To follow ocean wave groups into the MIZ to estimate the damping of wave energy based on the ice density and scattering from ice floes.
4. To correlate the open ocean wind and wave climate to the wind and wave climate within the MIZ using satellite SAR imagery and marine radar data.

APPROACH

Boundary layer flows and air-sea fluxes in ice infested waters like the MIZ are very complex compared to the open ocean where surface waves provide the only roughness at the interface. In addition freezing and melting cycles modify both the interface surface and the local transport of heat and mass which can readily be disturbed by the impact of surface waves penetrating the ice floes of different ice types. While obtaining measurements of the boundary layer flows in densely floating ice waters is

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challenging, a better approach might be with a nautical X-band radar installed on a ship. For example, the new ice breaking capable *R/V Sikuliaq*, currently built for NSF, could be equipped with a WaMoS system that is capable of making real time measurements of directional ocean wave spectra to monitor the sea state surrounding floating ice especially as the vessel enters the MIZ. Figure 1 shows a photo of the MIZ in Antarctica and highlights the interaction of wave action with ice. The MIZ is formed as a result of wave-ice interaction where waves break up the continuous ice. While this breaking process is not indefinite, the extent of the MIZ will depend on the wave energy which itself is attenuated throughout this interaction process.

Figure 1: Photo of the MIZ in Antarctica taken from the bridge of a vessel (Meylan 2003).

Single waves and wave groups are retrieved from several WaMoS II image sequences which can be inverted into sea surface elevation maps using the method by Nieto-Borge *et al*. (2004). The X-band data can also be used to compute local wind field maps (Lund *et al*. 2012) which would also identify the presence of ice floes. Similarly surface currents can be determined from sequences of radar images using the dispersion relation of high frequency wave modes. A marine radar would also detect the presence of floating ice and in combination with satellite SAR imagery could provide local validation of the observed wind and wave conditions. Figure 2 from the Canadian Coast Guard (O'Connell 2012) shows a radar image of floating ice and icebergs off the coast of Greenland. Marine X-band radar in short pulse mode can easily detect the shapes of ice floes and rafted ice as well as open water leads where backscatter should indicate the presence of ocean waves.

The Wave Monitoring System WaMoS II is an ocean wave and surface current monitoring system designed for operational measurements under harsh environmental conditions. Many offshore operations are critically dependent on the prevailing sea state. To enhance the safety of people, structures and environment, routine sea state as well as surface current measurements are required. WaMoS II is an instrument especially designed to measure in real time sea state information such as significant wave height, wave period and wave direction. It can be operated automatically and

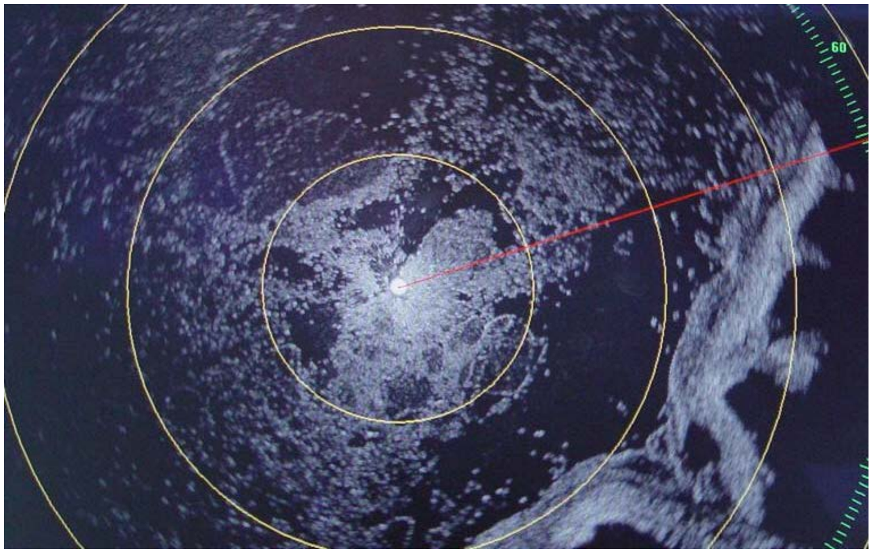

Figure 2: A marine radar image showing the presence of ice floes and open water leads off the Greenland coast.

unattended from moored platforms, moving vessels or coastal sites. As the system is not in direct contact with the sea, it is optimally suited for use under extreme weather and sea state conditions. Standard methods are applied to derive directional wave spectra from a sequence of nautical radar images and then compute standard wave parameters like significant wave height, peak wave period, peak wave direction and peak wave length. The measurement and data analysis takes about 2 minutes for standard, commercial nautical radars and sea state parameters are available in real time. A minimum wind speed of 3 m/s is required to obtain good wave measurements. Figure 3 shows two radar images recorded at different sea states. Clearly the intensity of the backscatter will change with height of the waves and the strength of the wind.

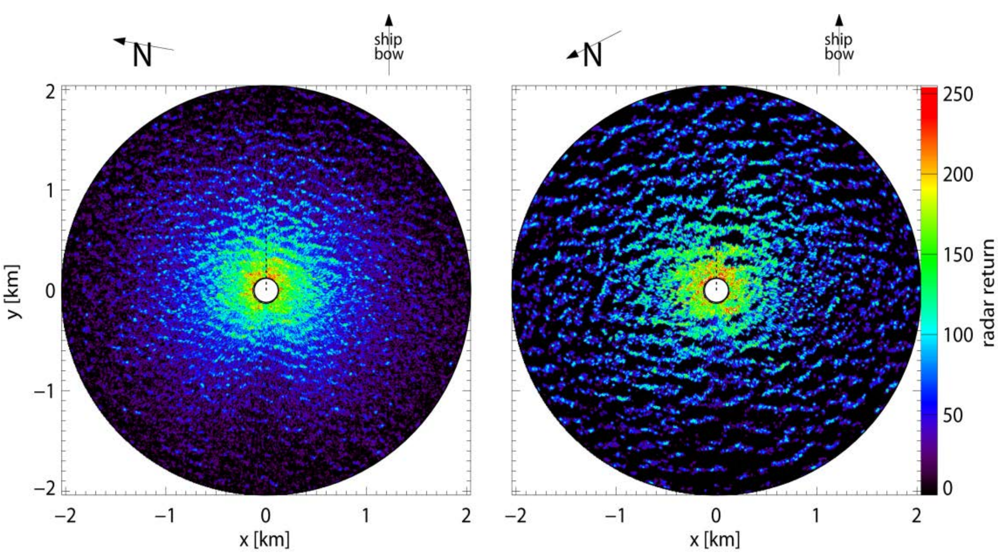

Figure 3: Radar images collected by WaMoS on the 2 Sep 2006, 01:00 UTC (left) and 12:00 UTC (right). The radar return is color coded.

The WaMoS II system is capable of making real time measurements of directional ocean wave spectra to monitor the sea state from fixed platforms in deep water or coastal areas and from moving vessels even at high speeds. Spectral sea state parameters such as significant wave height, peak wave period and peak wave direction both for windsea and swell are derived. A new algorithm has been developed to determine sea surface elevation maps from radar images which are used to investigate the spatial and temporal evolution of single waves simultaneously.

Single waves and wave groups are retrieved from several WaMoS II image sequences which were inverted into sea surface elevation maps using the method by Nieto *et al*. (2004). The resulting maps have the same spatial and temporal resolution as the radar sequences. A directional wave finding algorithm (DWFA) is then used to identify single waves in inverted radar images. The individual waves, wave crests and troughs as obtained by DWFA, are localized and analyzed to determine wave propagation characteristics. This approach will provide a deterministic description of the wave field from the X-Band raw image data and the total number of single waves within a radar image. These results could be used to test the ability of wave resolving models to describe correctly the physics and propagation characteristics. In addition, surface currents can also be determined on a high resolution grid that allows direct examination of wave-current interactions.

Figure 4 shows the marine radar backscatter image and the subsequent products that can be directly generated from the raw data. These products include: a) surface elevation of individuals waves, b) directional wave spectrum, c) wind speed and direction, and d) surface current vectors.

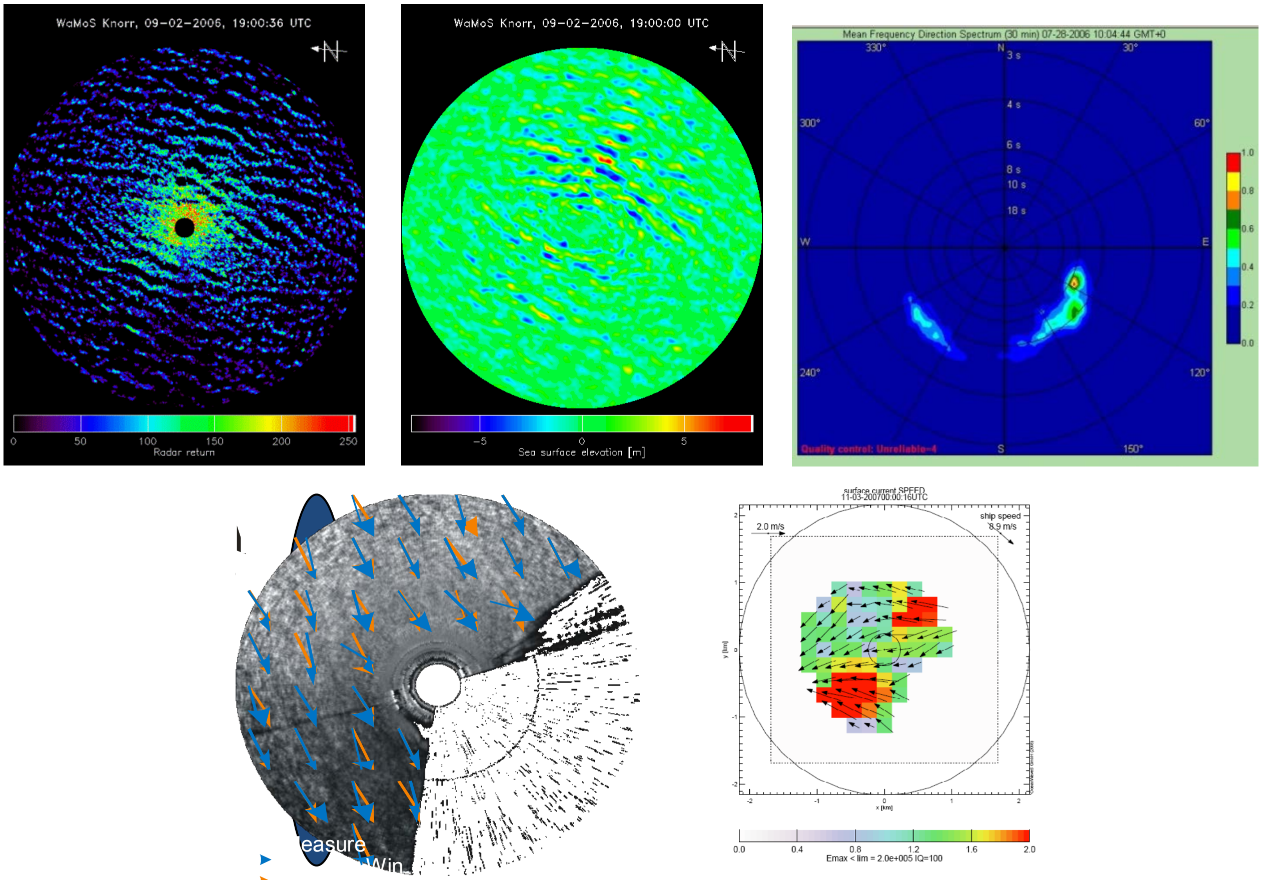

Figure 4: Top left: Marine radar backscatter image. Top center: Inverted radar image to generate a surface elevation map. Top right: Directional wave spectrum. Bottom left: Wind speed and direction. Bottom right: Surface current vectors.

WORK COMPLETED

Currently this project is in its planning phase and we have participated in meetings and the development of a science plan. We are also advising ONR on the acquisition of a natuical X-band radar to be placed on the *R/V Sikuliaq*.

RESULTS

None.

IMPACT/APPLICATIONS

None.

RELATED PROJECTS

Monitoring of Arctic Conditions from a Virtual Constellation of Synthetic Aperture Radar Satellites
N00014-12-1-0448

REFERENCES

Lund, B., H.C. Graber, R. Romeiser, 2012: Wind Retrieval from Shipborne Nautical X-Band Radar Data. *IEEE Trans. Geosci. Rem. Sens.*, in press.

Meylan, M.H., 2003: Wave Scattering in the Marginal Ice Zone. *Proc. 18th Int. Workshop on Water Waves and Floating Bodies*. 6-9 April 2003, Le Croisic, France.

Nieto-Borge, J.C., G. Rodríquez Rodríguez, K. Hessner, and P. I. González, 2004: Inversion of marine radar images for surface wave analysis," *J. Atmos. Oceanic Technol.,* **21**(8), 1291–1300.

O'Connell, B., 2012: Marine Radar for Improved Ice Detection. Canadian Coast Guard Report. 6 pp.